MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1989

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries ninth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1989, ninety-two sampling trips were made aboard commercial lobster vessels. A total of 45,499 lobster were sampled from 15,047 trap hauls. The catch rate of marketable lobster, 0.751 lobster per trap, was 8% lower than the exceptionally high 1988 index, 0.820. The proportion of females ovigerous, 11.0% was significantly larger than the 1988 index of 8.8%. Coastwide fishing mortality and exploitation rates were equal to 1988 data. Mean carapace length of marketable lobster increased by 0.7 mm in response to the second gauge increase of similar size. The percentage of culls increased from 18.2% in 1988 to 19.2% in 1989. The percentage of lobster observed dead in traps was <1%, consistent with previous years.

The incidence of V-notched lobster in Massachusetts coastal waters was described by number and weight for the period 1984-1989. Annual and regional trends are discussed.

An assessment of the impact of the second of four 1/32" (0.79 mm) gauge increases indicated that the proportions of lobster in the larger market weight categories improved during 1989. Increased catch rates of egg-bearing females by 10 mm size groups were also observed.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) ninth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling-survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1988 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1989 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm and to the nearest 0.1 mm between 81.5 and 82.5 mm to establish the minimum legal size of 82.55 mm, 3.25"); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations and depths were recorded from LORAN and depth sounder equipment when available on vessels.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred to the Woods Hole Oceanographic Institution's Digital Equipment Corporation VAX-11/780 computer system for analysis. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

The Kolmogorov-Smirnov two sample test and Mann-Whitney U/Wilcoxon W tests were used to determine the significance of year to year variation in parameters.

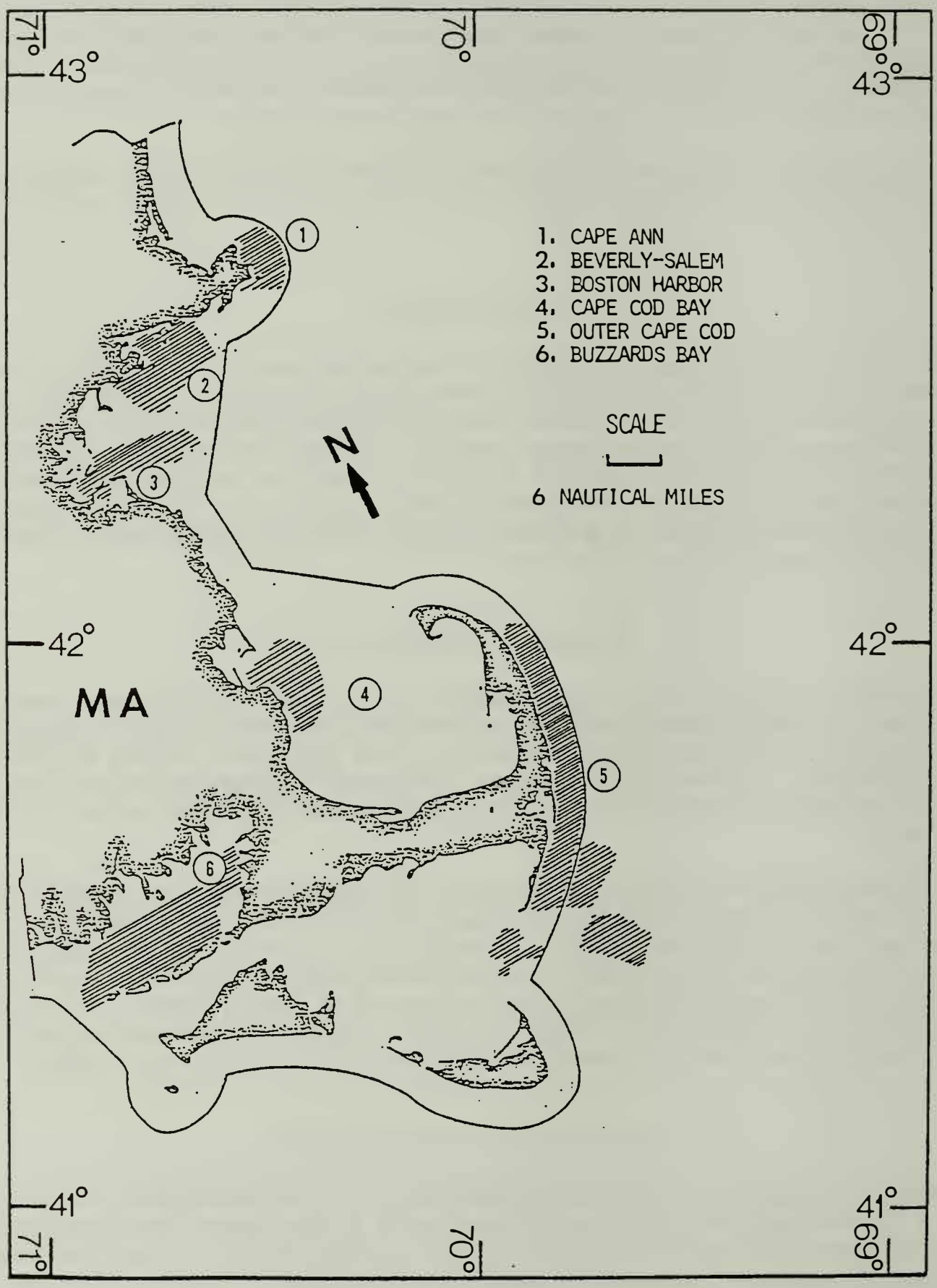

Figure 1. Map of Massachusetts coast with six sampling regions (hatch-marked) and territorial boundary line.

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighing scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females and, beginning in 1988, also excludes V-notched females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to the survey mode of 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with Cohort Analysis (Pope 1972). Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

During the period of May through November, 1989, ninety-two sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 45,499 lobster were sampled from 15,047 trap hauls.

The 1989 coastwide mean catch per unit effort index (CTH'_3), 0.751 marketable lobster per trap, was 8% lower than the 1988 index, 0.820 (Appendix Table 1). Total Massachusetts commercial landings (14,758,250 lbs) increased by 3% from 1988. Landings from inside 41° N 69° W increased by 5.6%, while landings from territorial waters increased by 7%. Offshore landings declined by 10%. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster increased between 1988 and 1989 (Appendix Tables 2 and 3).

Of all females sampled during 1989, 11.0% were ovigerous compared to 8.8% in 1988 (Appendix Table 4). The difference between years was highly significant ($P < 0.0001$). This represents the highest percentage of females ovigerous observed in the nine year monitoring period. Trends in abundance of ovigerous females are depicted in Figure 3 (Appendix Tables 4-6).

Fishing pressure indices decreased slightly during 1989 compared to 1988 (Appendix Table 7). Approximately 93% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits, i.e., lobster which

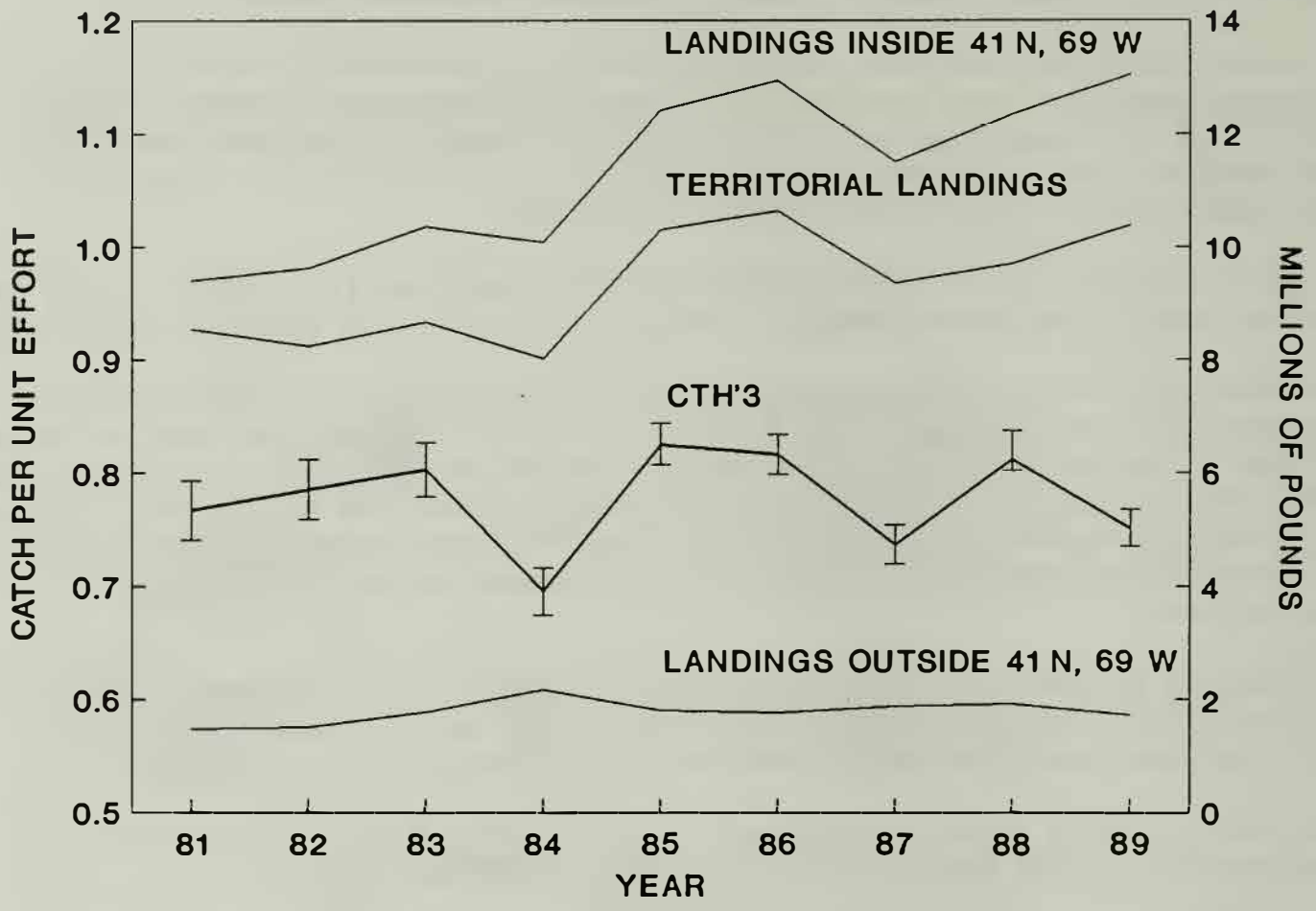

Figure 2. Catch per unit effort of marketable American lobster from commercial lobster trap sampling and Massachusetts lobster landings, 1981-1989.

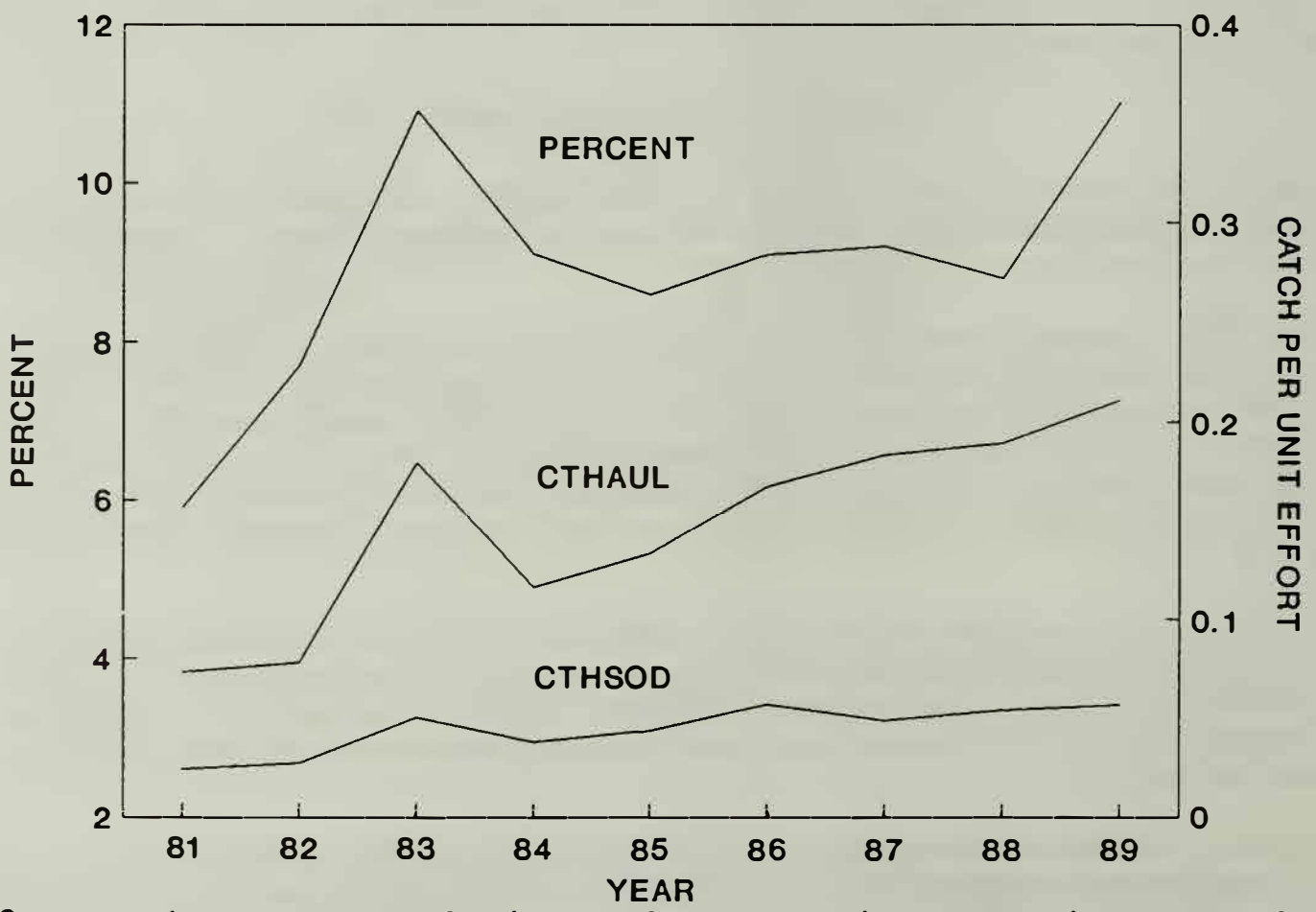

Figure 3. Relative abundance of ovigerous female American lobster in percent of total females and catch per unit effort, Massachusetts coastal waters, 1981-1989.

were sublegal before their most recent molt compared to 95% in 1988. The index declined from 57% to 47% for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) were also high, but they did not change much from 1988. Indices for inshore Gulf of Maine regions (Z = 1.27-3.59, A = 72%-97%) and Buzzards Bay (Z = 2.14-3.13, A = 88%-96%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.62, A = 46%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.54 off outer Cape Cod to 1.95 in Buzzards Bay (Appendix Table 9). An overall increase occurred during the nine-year study period. A similar trend was observed for the time series of exploitation rates (u), i.e. the fraction of the population that is removed by fishing (Appendix Table 10). Exploitation rates were highest in Boston Harbor and Buzzards Bay regions.

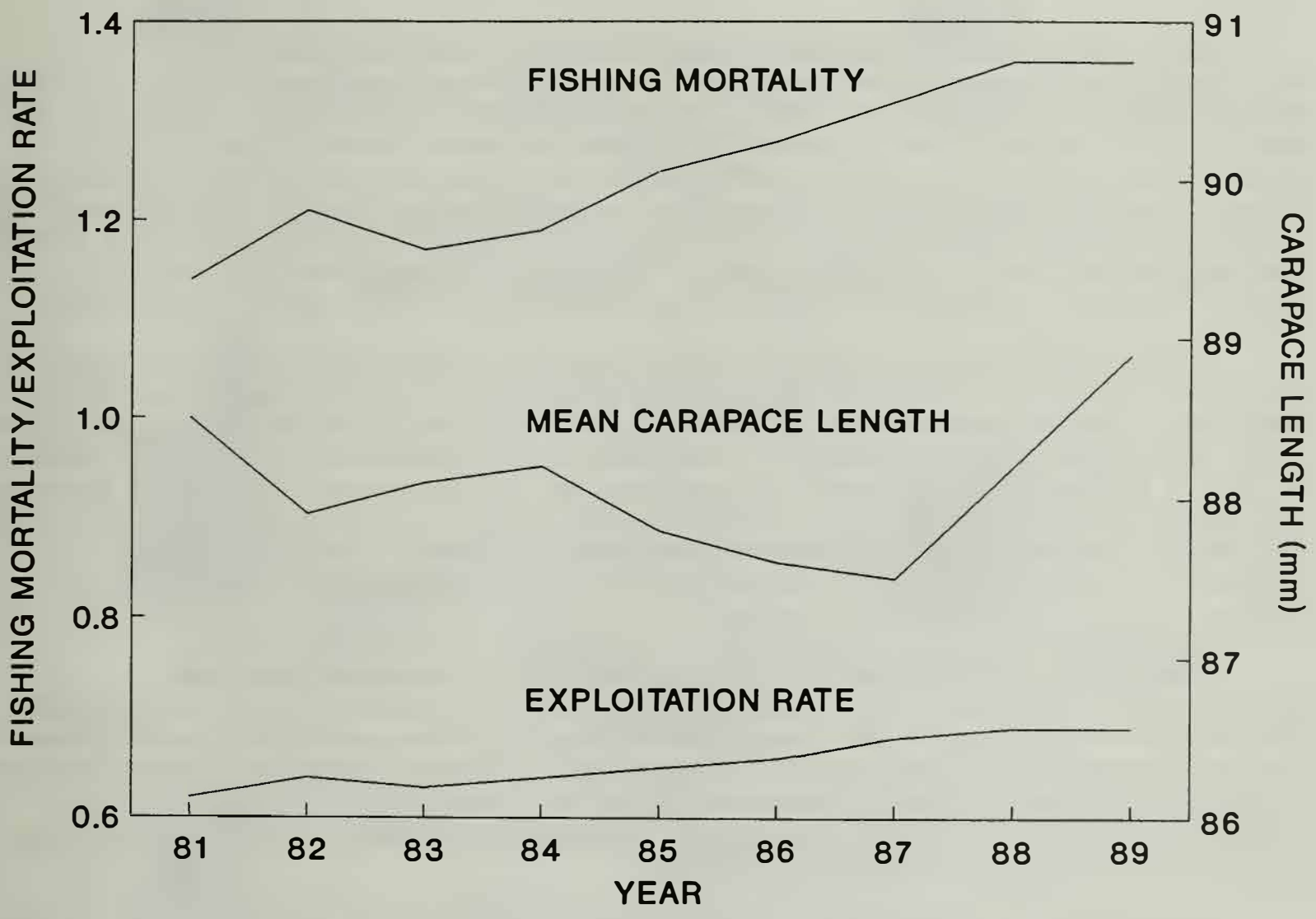

Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1989.

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter carapace length increases of 0.7 mm occurred in 1988 (88.2 mm) and 1989 (88.9 mm, Appendix Table 11) which probably reflect the similar numerical change in the minimum legal size during those years. Fishing mortality and exploitation rates appeared to stabilize accordingly.

Sublegal sized lobster averaged 77.5 mm carapace length during 1989 compared to 76.3 mm during 1988 (Appendix Table 12). The mean size of all ovigerous females increased from 87.2 mm in 1988 to 88.5 mm in 1989 (P = 0.001, Appendix Table 13).

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled increased from 18.2% in 1988 to 19.2% in 1989 (Appendix Table 14). This was due primarily to the increased cull rate of sublegal lobster (Appendix Table 17). The cull rates for legal and marketable size groups declined by less than 1% (Appendix Tables 15-17).

The coastwide incidence of lobster found dead in traps was < 1%. This was consistent with 1988 data (Appendix Table 18).

V-Notched Lobster

Since 1984 we have monitored the incidence of V-notched females in the commercial catches sampled in Massachusetts coastal waters (Estrella and McKiernan 1989). We infer from the knowledge of lobster movement acquired from tagging studies, that the majority of V-notched females observed originated in Maine where V-notching is an industry-sponsored practice. Maine state officials purchase and release female lobster that extrude eggs while in captivity at dealerships or coastal impoundments. Before release, the lobster are marked with a V-shaped cut in the right endopodite uropod (tail flipper to the right of center when head is facing away). This brands them as illegal to take. Many Maine lobstermen, although not required, also V-notch trap-caught egg-bearing females.

Beginning in 1941, Massachusetts DMF personnel were required to V-notch and return to sea female lobster after egg hatching occurred at the DMF hatchery on Martha's Vineyard. This law was amended on 30 March, 1959 to allow all licensed fishermen to V-notch egg bearing lobster voluntarily. The statute was repealed on 27 April, 1973 because of fear of gaffkemia induction at the wound site and a growing sentiment among managers and scientists that there were more definitive and measurable ways to manage the resource. Although a few Massachusetts fishermen continued to practice V-notching it is highly unlikely that they could account for the number of V-notched females observed in our studies.

On 1 January, 1988 V-notch protection once again became regulated in Massachusetts. This occurred in conjunction with the New England Fishery Management Council's implementation of the gauge increase program and extension of V-notch lobster protection throughout federal waters. The premise of uniform management throughout the range of the lobster was thereby supported by the adoption of this FMP amendment. Fishermen are currently required to return V-notched females to sea; however, there is no provision in the law for renewal of notching.

V-notched females are most abundant in two of the six Massachusetts coastal regions sampled, Cape Ann and outer Cape Cod (Figure 5). This is due to the migratory nature of these generally large mature lobster in the Gulf of Maine. They seasonally enter the deep water near Cape Ann and outer Cape Cod from which they move into adjacent shoals as the water temperature rises in the spring and summer.

V-notched lobster are generally larger than the normal marketable lobster, because the size at 50% maturity for northern Gulf of Maine females (the assumed source of most notched females) is around 100 mm CL. It is therefore desirable to express the proportion of lobster V-notched by weight as well as by number to assess the impact of the V-notch protection law on landings.

The following regional weight-length relationships were derived from 4,933 non-cull

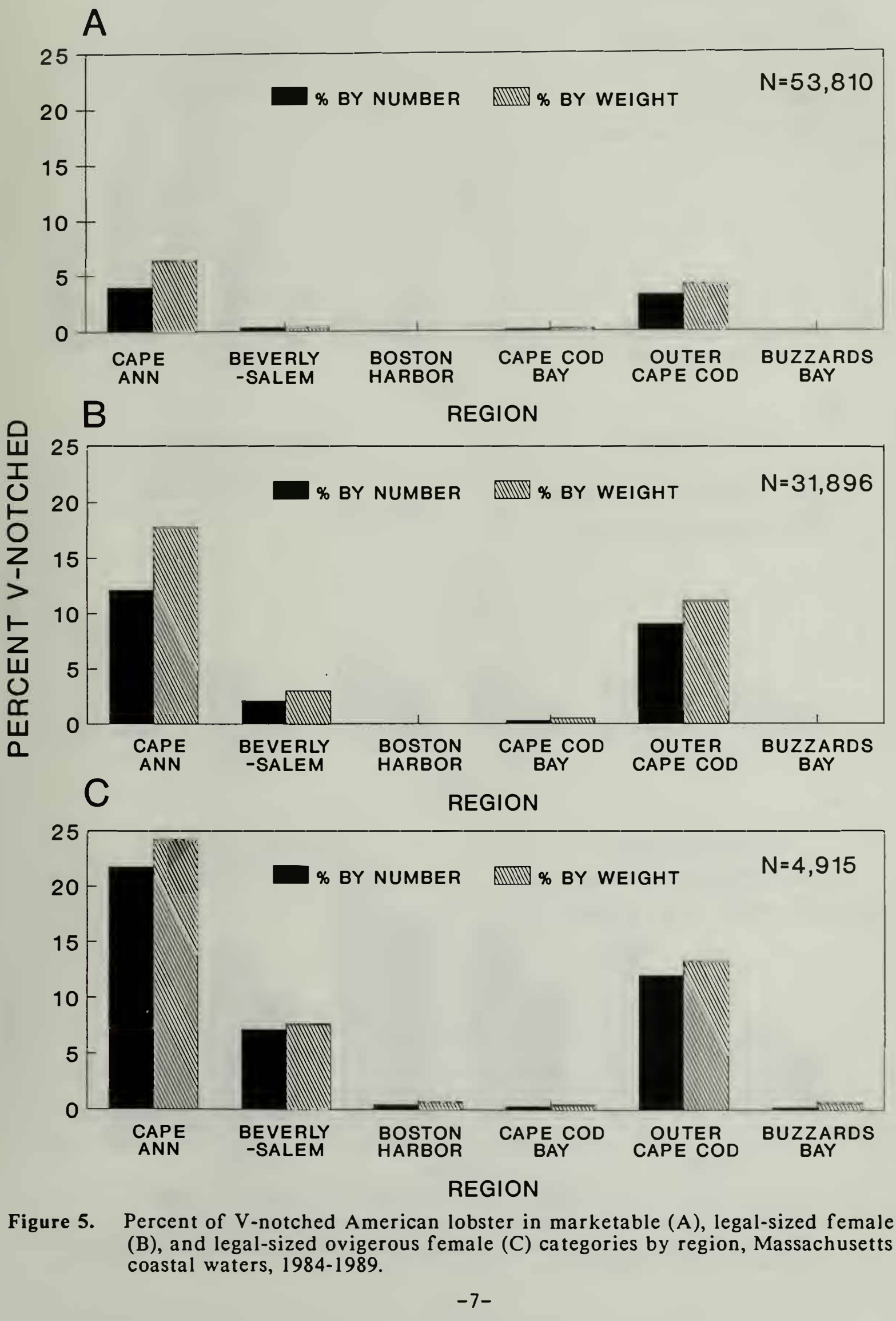

Figure 5. Percent of V-notched American lobster in marketable (A), legal-sized female (B), and legal-sized ovigerous female (C) categories by region, Massachusetts coastal waters, 1984-1989.

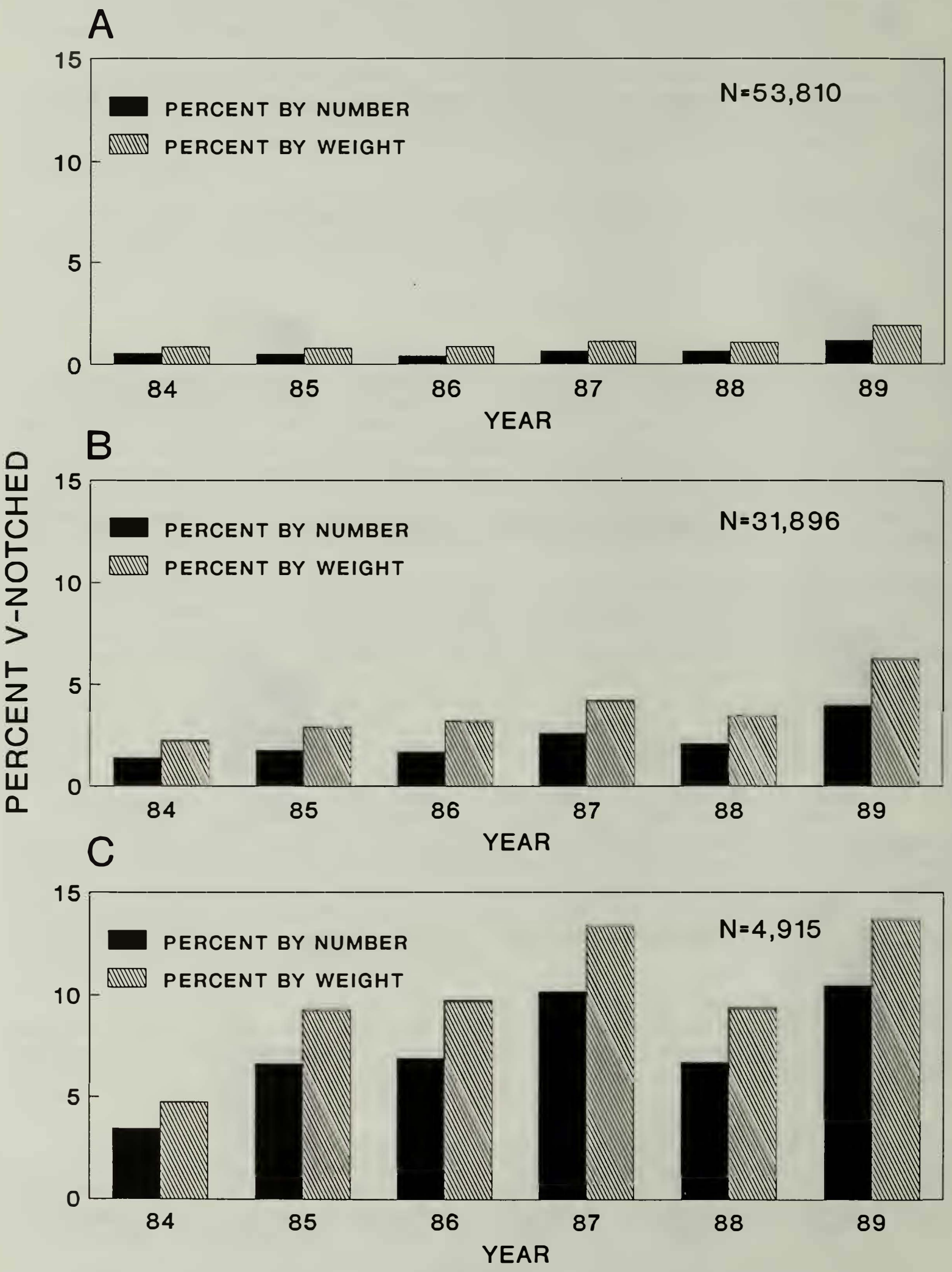

Figure 6. Percent of V-notched American lobster in marketable (A), legal-sized female (B), and legal-sized ovigerous female (C) categories by year, Massachusetts coastal waters, 1984-1989.

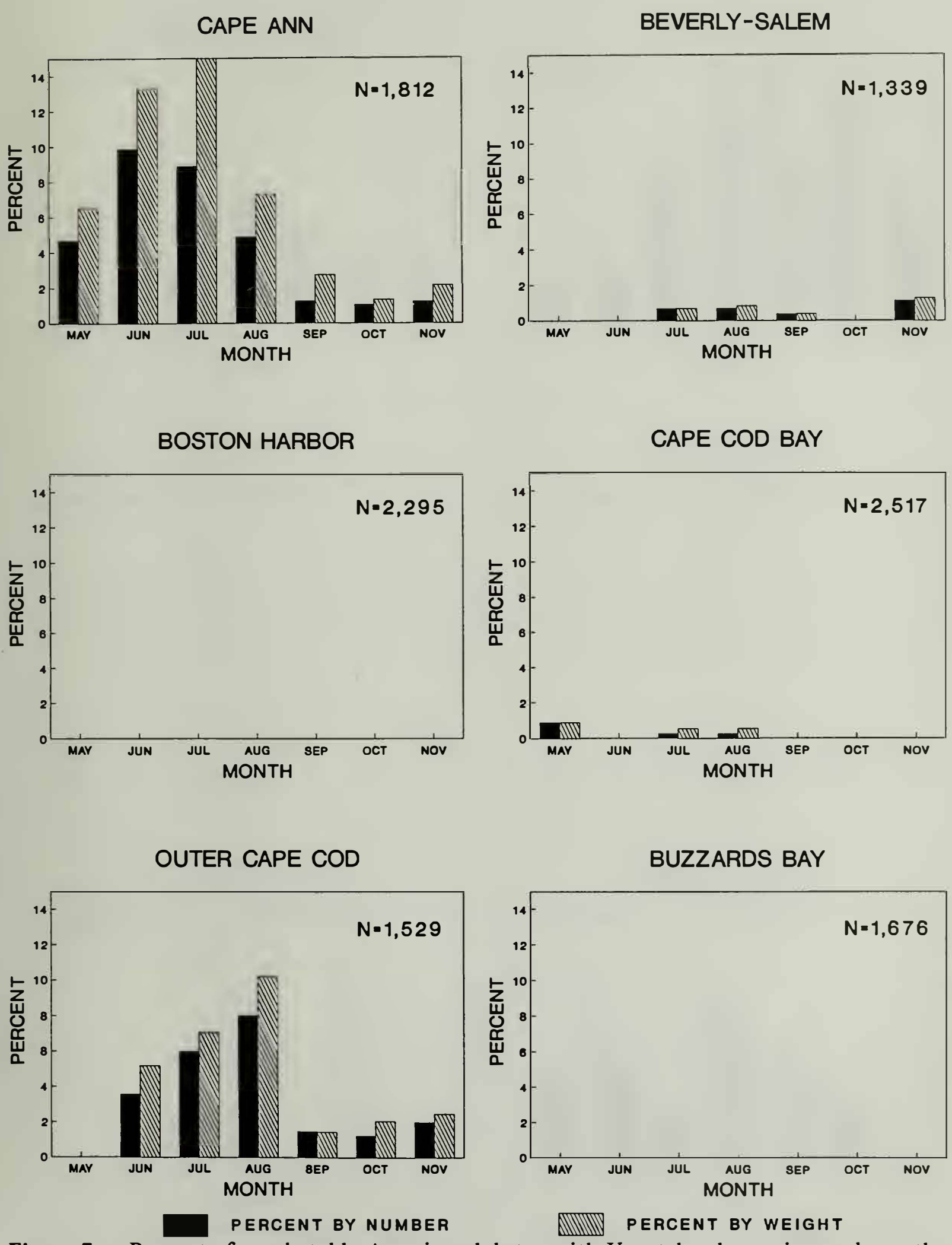

Figure 7. Percent of marketable American lobster with V-notches by region and month, Massachusetts coastal waters, 1989.

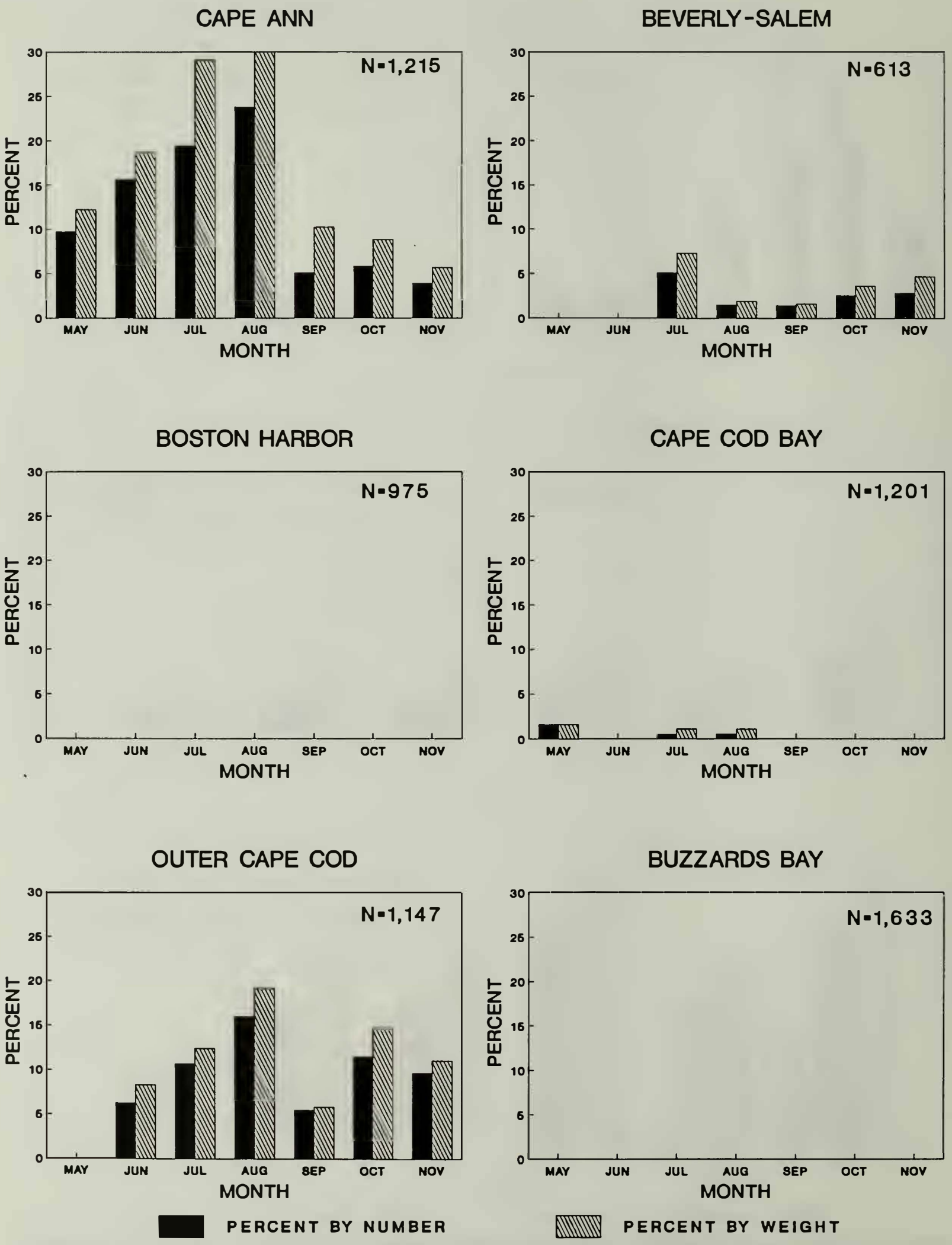

Figure 8. Percent of legal-sized female American lobster with V-notches by region and month, Massachusetts coastal waters, 1989.

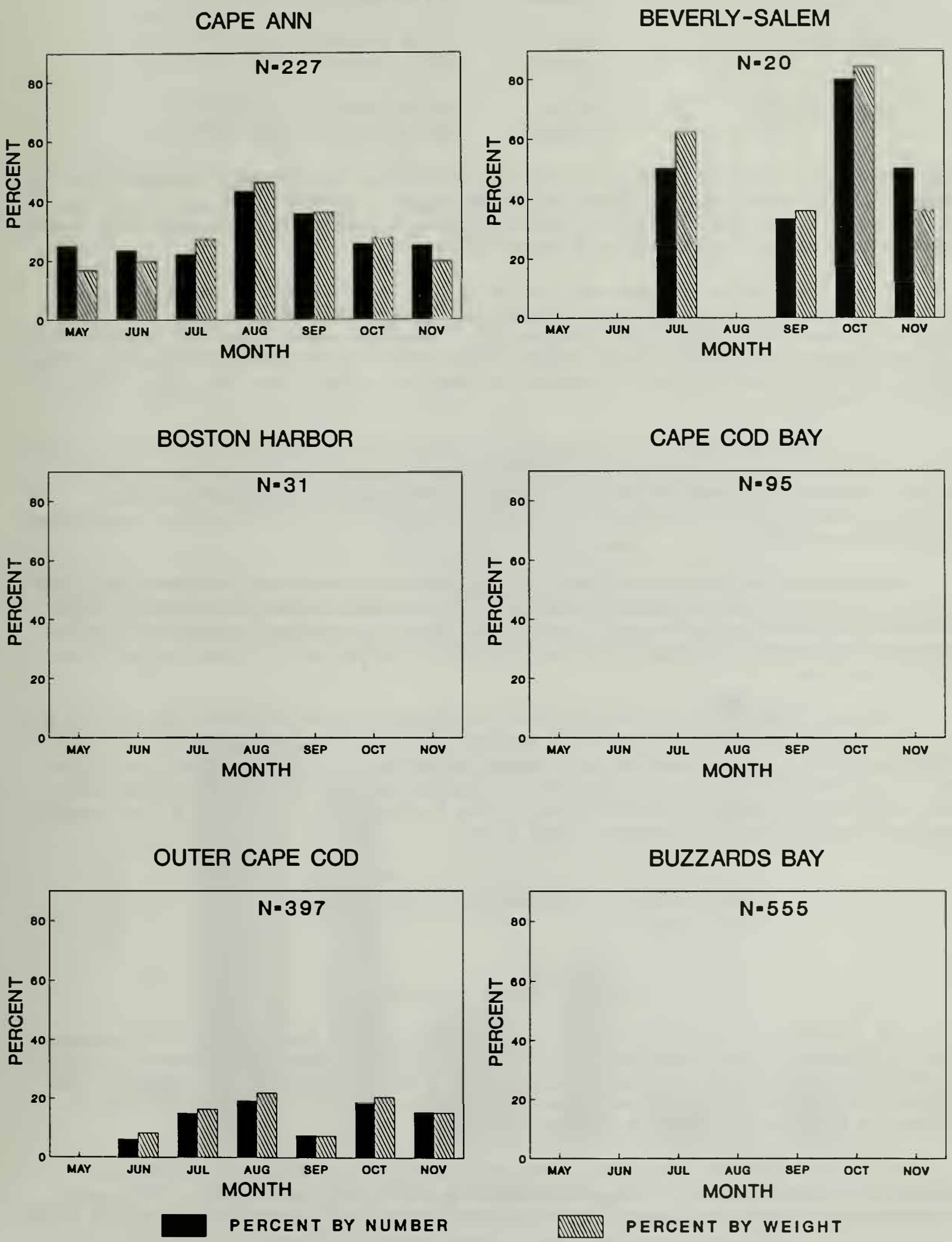

Figure 9. Percent of legal-sized ovigerous female American lobster with V-notches by region and month, Massachusetts coastal waters, 1989.

observations which were originally reported by Estrella and McKiernan (1989):

Southern Gulf of Maine	Males	$WT = 0.000344 \times CL^{3.1900}$
	Females	$WT = 0.001167 \times CL^{2.9194}$
Outer Cape Cod	Males	$WT = 0.000883 \times CL^{2.9868}$
	Females	$WT = 0.002114 \times CL^{2.7990}$
Buzzards Bay	Males	$WT = 0.000162 \times CL^{3.3762}$
	Females	$WT = 0.001575 \times CL^{2.8697}$

These equations were used to calculate weights for all legal-sized lobster measured during commercial trap sampling from 1984-1989 by sex, region, and cull condition. Predicted weights were then reduced for lobster with missing or regenerating claws according to cull lobster weight deficits calculated by Krouse (1976).

V-notched females represented from 0.4 to 1.16 % (0.79-1.86% by weight) of the coastwide marketable catch (less eggers) between 1984 and 1989 (Figure 6A). The coastwide proportion of legal-sized females with V-notches ranged from 1.33 to 3.94% (2.21-6.25% by weight) during the six-year period (Figure 6B). The percentage of legal-sized egg bearing females (Figure 6C) with V-notches was higher ranging from 3.46 to 10.42% (4.73-13.66% by weight).

The overall increase in V-notched lobster observed in 1989 (Figure 6) may have been due to the impact of law enforcement and fishermen's compliance in the discard of V-notched females. This would make these lobster more visible in subsequent catches. However, some local lobstermen have renewed the practice of V-notching thus augmenting the number available.

Analyses of 1989 data by month generally show that V-notched lobster abundance tends to peak around mid-summer (Figure 7-9). This is likely due to their annual inshore movement into warmer shoal water. At this time they may represent as much as 8-10% of the marketable catch in number of lobster (10-15% by weight) in the Cape Ann and outer Cape Cod regions.

Industry concerns about variable interpretation and enforcement of the V-notch law and its impact on catches, particularly in the Outer Cape Cod region where large lobster predominate, led to the refining of the V-notch definition. In order to reduce confusion due to the potentially significant changes in the morphology of the V-notch which can occur from healing, molting, and shell disease, the Marine Fisheries Advisory Commission approved the following definition in April 1990:

> *"... a straight-sided triangular cut without setal hairs, at least 1/4 inch in depth and tapering to a sharp point."*

Gauge Increase Assessment

On 1 January, 1988 a five-year gauge increase program was initiated for American lobster. This change was promulgated by the New England Fishery Management Council in cooperation with the lobster-producing states in New England and the Mid-Atlantic. The minimum legal carapace length was raised from 81 mm (3 3/16") to 81.8 mm (3 7/32") in 1988 and to 82.6 mm (3 1/4") on 1 January, 1989.

An approximate 8% short-term loss in number of lobster was predicted for the Massachusetts inshore fishery during the beginning of the first year (1988) of the gauge increase program. This short-term loss was expected to diminish as recruitment from

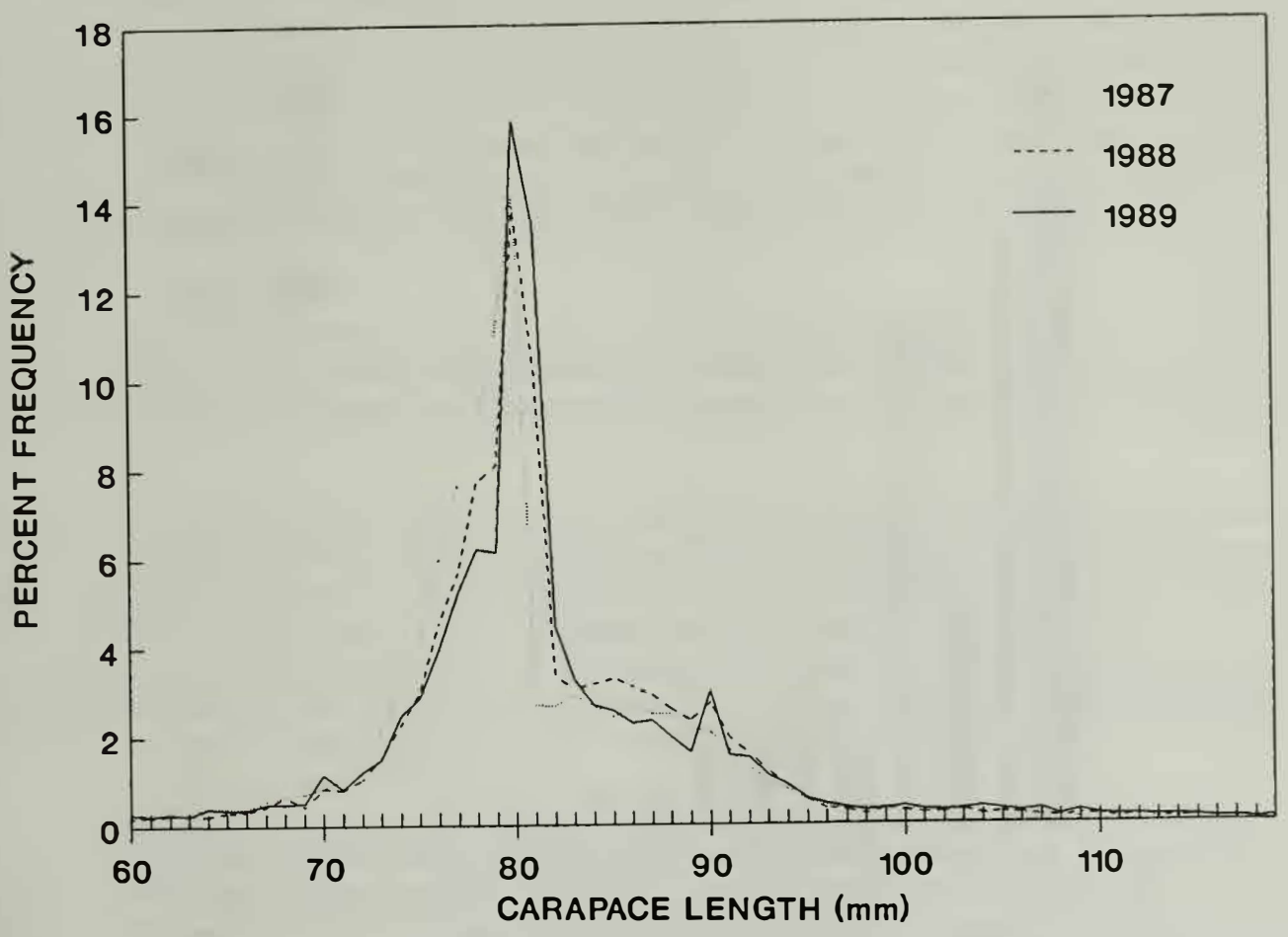

Figure 10. American lobster carapace length frequency from commercial lobster trap sampling, Massachusetts coastal waters, 1987-1989.

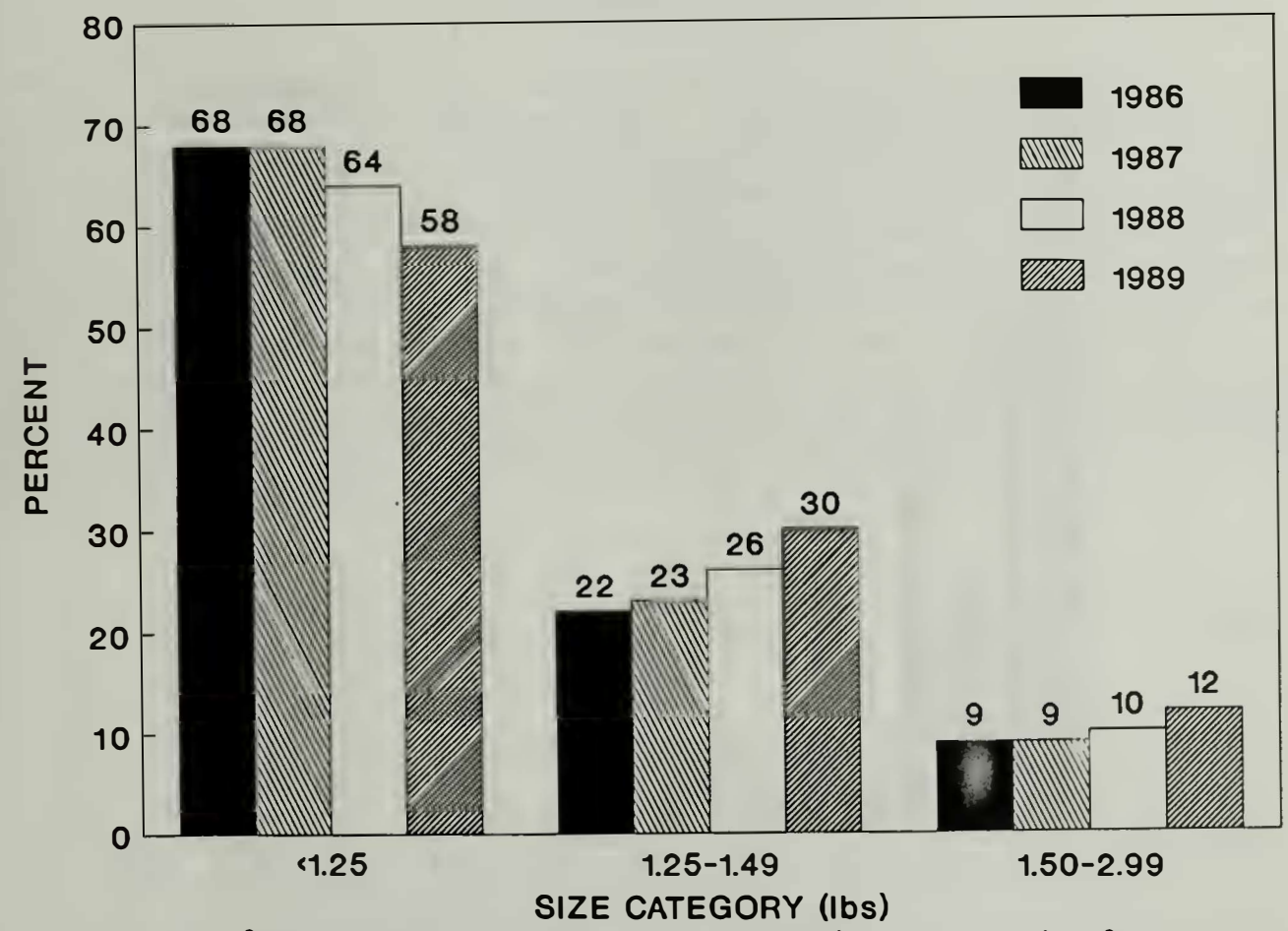

Figure 11. Percent of marketable lobster by market weight categories from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1989.

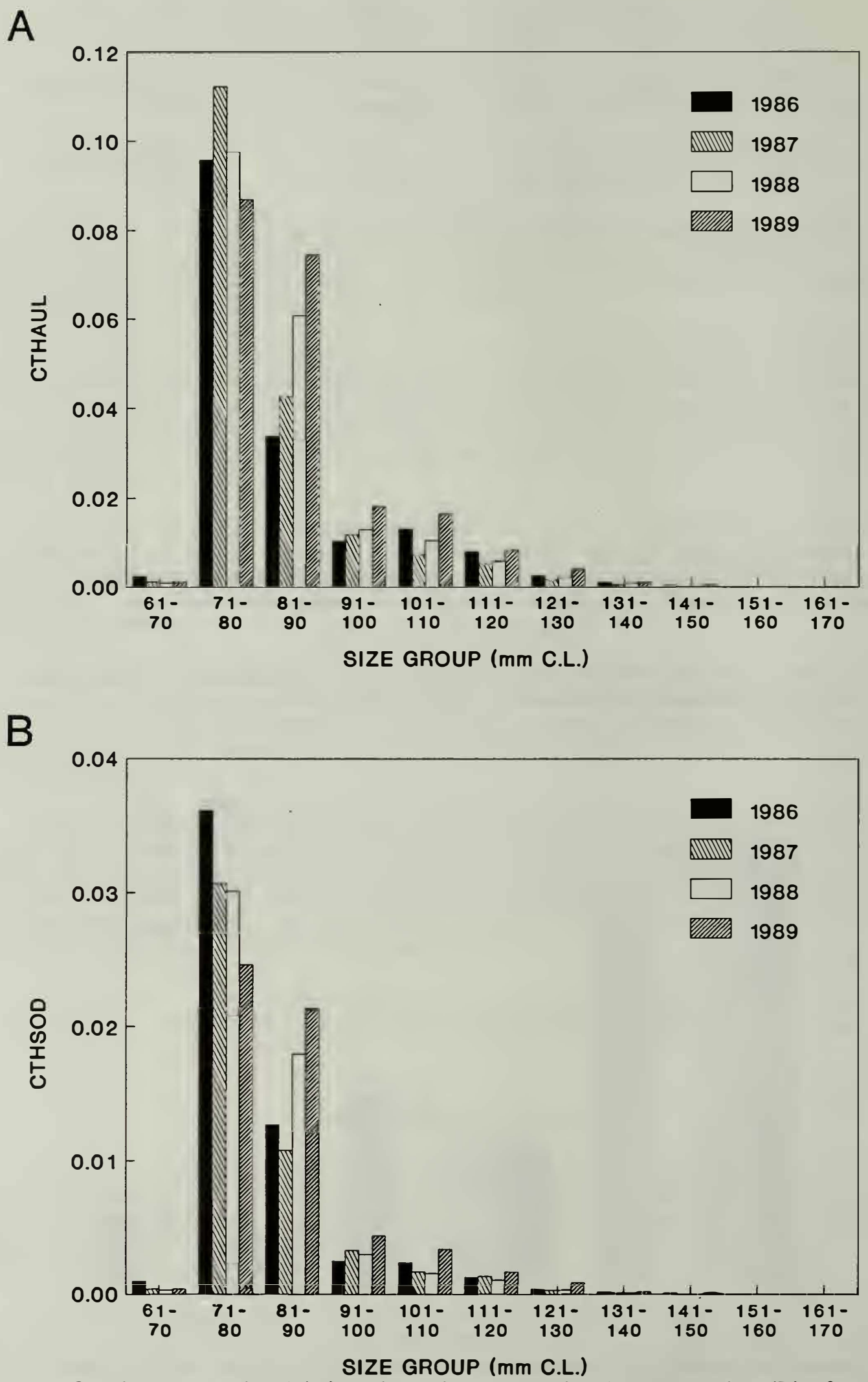

Figure 12. Catch per trap haul (A) and catch per trap haul set-over-day (B) of ovigerous female American lobster by 10 mm size groups, from commercial lobster trap sampling, Massachusetts coastal waters, 1986-1989.

molting adjusted the size frequency. Estrella and Cadrin (1989) reported that the 1988 lobster fishery was not impacted as expected due to excellent recruitment of sublegal lobster into the legal size range. However, an 8% decrease in the catch rate of marketable lobster (by number) was observed in 1989. This may be partly due to expected short-term losses from the second increase compounded by a substantially lower catch in the Cape Cod Bay region which represents a significant proportion of our study area and, therefore, largely affects our coastal catch rate. This decline in catch per unit effort occurred uncharacteristically with a 3% increase in total landings. The predicted long term adjustment in the resource (relative to increases in the minimum size) which is characterized by an increase in yield may have contributed to the disparate increase in total landings.

The observed increase in the catch rate of sublegal lobster between 1988 and 1989 may be the result of increasing the minimum gauge size without a concurrent increase in the escape vent size. However, an increase in abundance of these pre-recruit lobster cannot be discounted.

One of the predicted benefits of raising the minimum legal size for American lobster was that growth overfishing would be alleviated by increasing yield per recruit. As the gauge increase program progressed during 1988 and 1989 the size frequency of lobster gradually adjusted to the new gauge dimensions via growth. A shift of the size frequency to larger sizes occurred (Figure 10). A graphical analysis of 1986-1989 size frequency data, converted to market weight categories, shows the improvement in 1988-1989 data. A slight decline in the chicken category occurred in conjunction with an increased proportion of 1¼ - 1½ lb. and 1½- 3 lb lobster (Figure 11).

An assessment of changes in the size structure of egg-bearing females was made with catch rates by 10 mm size groups for the years 1986-1989 (Figure 12). An increase in the relative abundance of ovigerous females was apparent in most 1989 size categories.

ACKNOWLEDGEMENTS

We are indebted to the many commercial lobstermen who are involved in this cooperative lobster resource monitoring effort. The success of this program is due primarily to their continued interest and cooperation. Unfortunately, we must refrain from naming them in order to protect the confidentiality of their catch information. Gratitude is also extended to Brian Kelly, Vincent Malkoski and Joe Battaglia of the Pilgrim Power Plant Project (funded by Boston Edison Company), Dan McKiernan, Thomas Hoopes and Brad Chase for data collection, Ann Spires for data entry, James Fair who administered the project and reviewed the manuscript along with Dan McKiernan, and Kim Trotto who supplied word processing assistance. We also thank Thomas Hoopes for his data entry software design and assistance in data quality control. Main frame data processing was supported by the National Marine Fisheries Service (NMFS) Northeast Fisheries Center, Woods Hole, MA.

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721
Beverly–Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639
Boston Harbor	—	—	—	1.108	1.254	1.096	1.058	1.057	1.123
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934

Table 2. CTHSOD, by state and region, for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.509	0.695
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670
Beverly–Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780
Boston Harbor	—	—	—	0.901	1.162	1.138	1.156	0.639	0.966
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188

Table 3. CTHAUL, by state and region, for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	1.473	1.401	1.624	1.389	1.705	1.899	1.873	1.736	2.297
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765
Beverly–Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477
Boston Harbor	—	—	—	2.773	3.038	3.314	3.334	1.959	3.104
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	11.0
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3
Beverly–Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6
Boston Harbor	—	—	—	1.4	1.2	2.0	1.7	2.0	2.1
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037
Beverly–Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009
Boston Harbor	—	—	—	0.009	0.007	0.015	0.012	0.012	0.010
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096
Beverly-Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039
Boston Harbor	—	—	—	0.030	0.025	0.050	0.037	0.038	0.043
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	86	87	86	86	88	88	89	90	88
Cape Ann	91	92	87	89	87	87	88	90	84
Beverly-Salem	89	92	94	88	96	96	97	98	96
Boston Harbor	—	—	—	93	94	96	96	96	96
Cape Cod Bay	90	93	92	94	93	94	92	94	94
Outer Cape Cod	46	43	42	38	48	46	54	57	47
Buzzards Bay	98	96	96	94	96	97	97	97	95

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	1.58 *	1.72	1.66	1.66	1.76	1.80	1.90	1.86	1.80
	79% **	82	81%	81%	83%	84%	85%	84%	83%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55
	81%	89%	82%	85%	86%	87%	84%	83%	79%
Beverly-Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59
	86%	88%	91%	93%	97%	97%	97%	96%	97%
Boston Harbor	—	—	—	2.52	3.59	2.60	2.77	2.86	2.96
	—	—	—	92%	97%	93%	94%	94%	95%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43
	92%	93%	91%	92%	90%	94%	90%	94%	91%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62
	35%	37%	34%	28%	41%	40%	55%	51%	46%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13
	95%	95%	99%	96%	97%	98%	97%	96%	96%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981–1988.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	1.35 *	1.45	1.39	1.41	1.47	1.49	1.54	1.56	1.53
	74% **	77	75%	76%	77%	78%	79%	79%	78%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27
	73%	75%	74%	78%	74%	73%	75%	78%	72%
Beverly–Salem	1.59	1.7	1.85	1.78	1.96	1.99	2.16	1.98	2.01
	80%	82%	84%	83%	86%	86%	88%	86%	87%
Boston Harbor	—	—	—	1.82	1.75	1.92	1.88	1.84	1.94
	—	—	—	84%	83%	85%	85%	84%	86%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97
	81%	85%	82%	87%	85%	85%	83%	85%	86%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62
	42%	42%	41%	41%	43%	42%	48%	48%	46%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14
	95%	92%	90%	89%	91%	91%	91%	94%	88%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12
Beverly–Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95
Boston Harbor	—	—	—	1.77	1.70	1.80	1.87	1.83	1.94
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95

Table 10. Estimated exploitation rate (μ), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63
Beverly–Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76
Boston Harbor	—	—	—	0.82	0.81	0.80	0.84	0.84	0.86
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3
Beverly–Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7
Boston Harbor	—	—	—	86.8	86.9	86.4	86.6	87.5	88.0
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4

Table 12. Mean carapace length (mm), by state and region for all sub–legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3
Beverly–Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4
Boston Harbor	—	—	—	77.1	76.9	76.9	76.5	75.6	76.8
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	88.5	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4
Beverly–Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2
Boston Harbor	—	—	—	82.1	84.0	81.3	82.3	83.7	83.0
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981–1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	10.0	10.8	10.7	14.8	18.1	20.9	17.0	18.2	19.2
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7
Beverly–Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6
Boston Harbor	—	—	—	13.3	19.3	19.1	16.9	16.3	13.8
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6

Table 15. Cull rate (percent), by state and region, for all legal-sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9
Beverly-Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7
Boston Harbor	—	—	—	10.1	16.2	15.8	12.9	13.1	9.9
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0
Beverly-Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9
Boston Harbor	—	—	—	10.2	16.2	15.7	12.8	13.1	9.9
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0

Table 17. Cull rate (percent), by state and region, for sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9
Beverly-Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8
Boston Harbor	—	—	—	14.5	20.5	20.0	18.0	18.0	15.2
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1989.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13
Beverly-Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14
Boston Harbor	—	—	—	0.00	0.03	0.03	0.23	0.09	0.03
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11